Teaching Inquiry-Based Chemistry

Creating Student-Led Scientific Communities

Joan A. Gallagher-Bolos

Dennis W. Smithenry, Ph.D.

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Foreword

One thing we have learned in over sixty collective years of teaching at levels varying from middle school to a large university is that students learn best when they are intimately involved in the process. In contrast, "talking at" students (lecturing) is one of the least effective ways to convey understanding. There is no doubt in our minds that true understanding of a concept is constructed by each individual in his/her brain. This "constructivist" learning only occurs effectively when the student is participating in a meaningful way in the learning process. We call this "active learning" and we believe this is by far the best way to achieve effective learning. Active learning is at its best when the students are actually responsible for their own learning with only minimal guidance from the teacher.

This delightful book exudes contagious enthusiasm for active learning that will inspire virtually any teacher to begin teaching this way and encourage those who have already used active learning in some way to venture even further down this path. Teaching in this style is difficult at first because it is so different from the way that most of us were taught. It is hard to actually let students make mistakes and find their own way through problems and situations. It is also scary at first because we worry about whether we are teaching enough content to prepare the students for increasing numbers of standardized exams and for college. Our experience is that teaching content with little understanding of the underlying concepts is almost useless in the long run. Helping students to learn to think creatively, communicate, and work in teams is much more important than having them memorize lists of facts or rules. But creative thinking is not something that you can give to your students. They must learn it on their own and one of

the best ways for them to do this is to make mistakes and figure out how to correct their mistakes on their own. Interrupting the exploration process by correcting students as soon as they start down the "wrong" road is one of the worst things a teacher can do. Let the students learn from their own mistakes. Closely related is the effectiveness of peer teaching. Why did we all learn so much in our first years of teaching? We found our misconceptions when we couldn't explain something to our students, and we fixed them by reading a text or talking to a colleague. This same thing happens in student groups as they attempt to solve a problem together.

The authors of this book understand the power of active learning and convey it effectively with enthusiasm and specific examples to help you do it in your own classroom. We hope you enjoy the stories, understand the frustrations, and become enthused about turning your classroom over to your students in many ways as you read this book.

—Susan and Steven Zumdahl

Introduction

During our first few years of teaching, we remember being drained and frustrated with how little students seemed to care about learning. They weren't concerned with being actively involved in experiencing science. It became apparent that somewhere in the past, they were conditioned to believe that textbooks and recipe-driven labs define science. They thought that all the questions had been asked and answered, and therefore their only job was to learn the facts. Because they had no ownership of the problems presented to them, they didn't want to apply the information. They acted like robots.

We didn't want this type of class climate. So we asked ourselves, "What can we do to motivate students to get involved, to want to learn, to be curious about what's being presented?" After a good deal of experimenting in the classroom with different teaching methods, we realized that when we introduced a project where the students had freedom and responsibility, they became active participants and actually enjoyed science! Our focus question then became, "Who's running our classroom?" We knew that if the students were running things instead of us, they would become involved.

So we slowly put them in charge by gradually handing over the reins to the students as the year progressed. We now have active participants taking lessons above and beyond where we ever expected them to go. Instead of robotic learners, we observe:

- Students who own their science experience
- Students who are responsible for the final outcome of all activities, including lab planning, experimentation, analysis of data, and presentations of conclusions
- Students who learn to use freedom constructively in a group setting

- Students who further develop their talents and improve on weaknesses
- Students who develop a well-rounded definition for science
- Students who have fun *doing* science

While writing curricula and implementing activities that build a self-sufficient scientific community, we have found ourselves to be:

- Teachers who act as guides rather than disseminators of information
- Teachers who step outside of traditional teacher roles
- Teachers who are comfortable allowing their students to make decisions
- Teachers who have fun

We have created the classroom described above in eight unique school districts throughout our teaching careers. We (Dennis and Joan) have collaborated on curriculum development for the past nine years, though we have taught in the same district only one year. The districts in which we have taught included the full spectrum of schools: inner city, suburban, upper-middle class, small population (200 students), large population (2800 students), etc. We have also seen these classrooms come alive at every level of science, from freshmen physical science to senior-level advanced placement chemistry. So it can be used in any school and in any classroom.

Our book is structured in five parts, each section sharing a selection of our teaching stories. This book describes the implementation of activities that slowly shift the balance of who's in charge, from teacher to student, as the school year progresses. The benefits of allowing the students to be in charge are explained with each story. Our overall goal is to illustrate how we've motivated the students to take an active role in their science experience, thus creating the classroom atmosphere described earlier.

SEPT	*Scientific Community*	*This Style of Teaching Incorporated All Year Long*
OCT	*Part. Nature of Matter & Gas Laws*	
NOV	*Atomic Structure & Per. Trends*	
DEC	*Reactions & Stoich.*	
JAN	*Stoich.*	
FEB	*Equilibrium & Thermo-chemistry*	
MAR	*Acids & Bases*	
APR	*Organic*	
MAY	*Soap*	
JUNE	*Finals*	

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Can This Style of Teaching Work?

"In your dreams! There's no way your class worked for two weeks without a teacher's direction. That could *never* happen!"

We imagine a good number of readers—like some of our coworkers have been in the past—are quite skeptical about the soap activity described in Chapters 1 and 2. First of all, yes, it really can happen. And second, yes, we know you have a number of logistical questions about how we get our classroom functioning in this manner.

Getting the students to work as constructively and efficiently as described in Chapter 2 takes us an entire school year. A given class requires eight months of practice to gain the content and skills necessary to successfully complete a project like "soap." But it can be done, with any class from any high school. To alleviate some of your anxiety, we'd like to address some of the most frequently asked questions from teachers who wonder how we can give a class so much freedom without allowing chaos to run rampant.

1. *How did you develop your inquiry-based teaching styles? Why do you teach like this?*

   Our teaching styles (Joan's and Dennis') are quite similar and are rooted in many unique life experiences. The most significant contributing factor that formed our inquiry-based approach to teaching science is simply that we remember how much fun it was as children to ask questions and explore. We've always loved science. We still find our environment fascinating and have maintained the ability to continually question the "how" and "why." It made sense to us to try to rekindle the same inherent curiosity in our students in order for them to have as much fun with science as we do. We share some stories in the beginning of Chapter 4 that will elaborate on this; in short, we want our enthusiasm and fascination for the mysteries of science to be contagious. So we do what we can to get our students hooked.

2. *What benefit is there to teaching this way as opposed to using a traditional approach in the science classroom? In other words, how do you align your teaching style with the standards?*

   First of all, we don't want to mislead anyone. We still use traditional teaching methods in our classroom. We lecture, do demos, assign homework including textbook reading, give tests, and do lab activities. However, we do try to limit lessons that only disseminate information or require students to regurgitate facts during the entire period. Instead, we use these traditional methods to supplement our more frequent inquiry-based lessons. Our goal is to get the students excited about doing science by, simply put, letting them do science! *Doing* science allows students to formulate good questions, design and perform true experiments, think critically about the outcome, draw an educated conclusion as to "how" and "why" something happened, and appropriately communicate these findings to a wide range of target audiences. These skills then lend themselves to every arena outside the science classroom.

   Coincidentally, the majority of our lessons align themselves with the standards given in the *National Science Education Standards*, published in 1996. Specifically, our approach to teaching aligns itself with the teaching standards A–F, as follows:

Teaching Standard A: Teachers of science plan an inquiry-based science program for their students.
Teaching Standard B: Teachers of science guide and facilitate learning.
Teaching Standard C: Teachers of science engage in ongoing assessment of their teaching and of student learning.
Teaching Standard D: Teachers of science design and manage learning environments that provide students with the time, space, and resources needed for learning science.
Teaching Standard E: Teachers of science develop communities of science learners that reflect the intellectual rigor of scientific inquiry and the attitudes and social values conducive to science learning.
Teaching Standard F: Teachers of science actively participate in the ongoing planning and development of the school science program.

The benefit of using the inquiry-based method of teaching science is clearly laid out in the follow-up document, *Inquiry and the National Science Education Standards* (2000). Our lessons are also impressively aligned with this additional call to incorporate inquiry-based teaching into science education programs. The council states that the research done on inquiry-based teaching "clearly suggests that teaching through inquiry is effective" (p. 126). The council further describes individual studies that were directed at special student populations around the world, showing: "A pattern of general support for inquiry-based teaching continues to emerge from the research." A university-level study (also mentioned on page 126), which we believe to be particularly interesting, found that regardless of scores, students learning through inquiry have a higher motivation to do science (Heywood and Heywood 1992).

3. *Do the students run the classroom right at the beginning of the year? Do you step back and put them in charge in September?*

Absolutely not. We take many factors into consideration when deciding how to get our students ready to function as a

self-sufficient scientific community. No class would be successful being completely on its own at the beginning of the year. We guide our students through the steps necessary to function effectively without us. Some classes pick up on these skills more quickly than others through the first few months. The level of students, the type of class, the personality and maturity of the students all play a role in the amount of freedom we're willing to offer at a particular point in the year.

At the start of the year, we give the class smaller projects and/or labs that take one to three days to complete. Specific examples of these activities are explained in Chapters 4 and 5 of the book. We help them establish a class climate that nurtures a community approach to solving problems. We guide them through projects by answering questions, facilitating discussions, suggesting problem-solving methods, and role-playing different characters that will help them accomplish a task. Once they have a solid foundation of the minimum that is expected, individually and as a class, we slowly remove ourselves from the equation. Rest assured, before turning them loose in a culminating end-of-the-year activity, we take it slowly, introducing them to all the skills and content necessary to succeed without the aid of a teacher.

4. *How do you get all the content in when you give the students so much time to "discover"?*

The *National Science Education Standards* includes the content standards A–G, as follows:

Content Standard A: Science as Inquiry
Content Standard B: Physical Science
Content Standard C: Life Science
Content Standard D: Earth and Space Science
Content Standard E: Science and Technology
Content Standard F: Science in Personal and Social Perspective
Content Standard G: History and Nature of Science

Our book provides an approach to teaching that squarely hits on content standards A and B. Some of our activities also briefly cover E, F, and G. These activities could easily be adapted for

whatever content area needs to be covered in other science classes, like those mentioned in content standards C and D.

Giving students time to discover does not always mean sacrificing content. As we've stated, we still have days where we lecture, do demonstrations, and run lab activities that are more teacher-directed. So we find ourselves still getting through the majority of the content outlined within a particular curriculum. However, we typically have an inquiry-based "twist" whenever we're giving a lecture or performing a demo, to keep the students thinking. For instance, when introducing the mole, we do not begin a lecture by defining the mole and spending a half hour explaining it to the students. Rather, we think of a focus question to get the students interested. For example, "There's a liter of water in this glass. Before I drink it, how many molecules of water do you think are in it?" We write their ideas on the board and hold a discussion on which answers seem reasonable. Students are asked to justify what "reasonable" means. Then we give a ten-minute lecture on the concept of the mole. Later we go back to the glass of water and challenge the students to answer the initial question. As a follow-up, more demos are introduced with probing questions, and homework practice problems are assigned. In this way, we get through the content using a variety of methods as the students develop a deeper understanding of the mole.

However, it is true that we sometimes must sacrifice one unit in order to allow the students to investigate another topic in depth. As teachers, it's been tough to let go of some of the content and decide which topics to cover and which to cut. No matter what teaching methods you use, there never seems to be enough time. However, research suggests that "this 'cover everything' approach provides few opportunities for students to acquire anything but surface knowledge on any topic" (Schmidt et al. 1997). Our focus is not only to get students to a point where they can act as scientists, but to also enjoy doing so at the same time. Teaching them an inordinate number of meaningless science facts does not accomplish this. But having them delve deeper into a unit gives them this opportunity. Less is more!

5. *What about the student who might be unwilling to actively participate in a class project once you've "handed over the reins"?*

   Most often, these unwilling students are more likely to participate when their peers are in charge. We have found that the class is sometimes more effective at creating an atmosphere where this type of student will want to participate. For example, Dennis had a disruptive student who tried his patience during teacher-led activities. However, when the student's peers were in charge, he would become quite cooperative and congenial. The students were familiar with his behavior from previous years and knew better how to work with him.

   Sometimes a student still remains unwilling to participate even with peers in charge. But this happens either way; with or without the teacher, this student is not going to do much of anything. And everyone recognizes that. The community learns to pick up the slack and get the job done. Think of a class with twenty-six students. In a student-led project with a nonparticipating student, the teacher is certain that twenty-five out of twenty-six students are actively involved. In a teacher-led lesson, the teacher would have proof concerning only the one nonparticipatory student. It's still uncertain whether the other twenty-five are actually involved with what you are teaching. So this represents a huge advantage in using inquiry-based, student-led activities.

6. *I'm still hesitant. When you say you're going to hand the class over to the students, I'm always concerned with time on task. Regardless of the length of a project—one day, three days, ten days—what internal motivation are your students using for the majority of the class to stay on task? Without prompting from me throughout a period, it seems surreal that they would actually stick to it. How do you get this to work?*

   It's not as difficult as you might think. We describe the beginning steps to this process in detail in Chapter 4. But simply put, if you trust them to do something and they know you believe that they can, and if you present the activity in an enthusiastic manner, they will typically respond by living up to your expectations. We were hesitant, too, the first time we "let go" and left them in charge. But we realized after the first activity we

tried, students are desperate for this opportunity. They're tired of being spoon-fed, even if they don't realize it at first. We didn't know what would happen because we had never tried it before and had never heard of anyone else trying it before. But after going through a couple years of letting our students *do science*, students at every level, we did not see chaos erupt, as most teachers predict. Instead, we saw students getting excited about science again, about being given the opportunity to control a bit of their own education.

There are certainly things you must do as a teacher to steer a class in the right direction at the beginning of the year to get students used to this new method of learning. One class may need nothing from you. This class takes on a personality that loves a challenge and will fly with any task you put in front of them. Another class may need some prompting questions or pictures drawn or charades to be played to get them on the right track. And still another class might need you to direct quite a few activities until they get the hang of it. After all these years of using this inquiry-based approach in our classrooms, we still experiment with what works for each unique class.

Another key ingredient in getting our students to build a scientific community and to stay on task while working as a class is for us to stay focused on preparing them for the final project. These are not isolated activities that we introduce to our classes. Every day they experience some individual and class accountability. They know it isn't going away, so they learn to work within the system we set up.

7. *How do you grade a class project?*

It's tough to answer this question with a blanket rubric for all class activities. Each project is unique. We did outline how the soap project is graded on the actual project sheet, Handout 3. It contains both individual and class grades. In general, we want to teach our students to develop an appreciation for the fact that both group and individual accountability is important. To be an effective member of a class/company, you must first be as prepared as possible individually. In terms of encouraging individual preparation, we

use traditional methods of assessment to see how well students are keeping up—quizzes, homework, tests, etc.

Although each project is unique, the grading of the class work is typically split into three categories:

A. The first is safety. During a class quiz, class lab, class project, or class test (examples described in detail in Chapter 5), the class is given credit for how well they follow safety procedures. This includes obtaining MSDS information on all chemicals involved, using proper lab technique, policing each other to make sure everyone is safe, having equipment ready in case of an accident (like baking soda for an acid spill), and proper cleanup of lab.
B. The second category is accuracy. We check the work that is turned in, just as we would an individual test, quiz, or lab, to make sure the responses are correct.
C. The third category is cooperation. We look for positive conversations, a constructive group effort, on-task behavior, and a high level of group intensity to get the challenges finished.

As an example of points given for these three categories, in a class test worth 12 points, each area (A, B, and C) is given equal weight of 4 points. Every student in the class would then receive the same number of points out of 12, since it was a class test.

In general, assessing an inquiry-based classroom and the activities that go along with it takes some practice. The *National Science Education Standards* list five areas to focus on:

Assessment Standard A: Assessments must be consistent with the decisions they are designed to inform.
Assessment Standard B: Achievement and the opportunity to learn science must be assessed.
Assessment Standard C: The technical quality of the data collected is well matched to the decisions and actions taken on the basis of their interpretation.
Assessment Standard D: Assessment practices must be fair.
Assessment Standard E: The inferences made from assessments about student achievement and opportunity to learn must be sound.

Reading these standards can be quite confusing and frankly very frustrating to follow. In our opinion, the best approach is to give the students feedback on all parts of their experiences in your class—from individual, content-focused tests to the journey a community takes while solving a problem. In this way the assessment will give both the teacher and the students information on where to go next in developing their scientific community.

8. *What has been the parental response to the idea of inquiry-based group work? How do they feel about group grades?*

As far as parental response to our group activities, it has been overwhelmingly supportive. Most parents understand that industry is based on collaborative work. They, like us, feel that individual accountability is still very important, but that students need to practice working toward common goals as a group. Together, we've had hundreds of parent letters and phone calls from all different districts praising the methods we use in our classroom.

The parents who are "concerned" about our group activities seem to call only regarding the grades their children receive that are group oriented. Combined, we have received a total of nine negative phone calls in reference to group grades. Over fourteen years and between two teachers, that's not bad. It's interesting to note that for all nine cases, the parents rescinded their concern when they learned that their child's grade went down after removing the group grades from their child's points. So this, in our minds, should not be a major concern as a teacher.

9. *What happens when I implement the activities described in this book and the goals are not achieved?*

The intention of this book is to provide you with the curricular foundation in implementing a constructivist approach into the science classroom. Certainly adjustments must be made to all activities presented here depending on the level of students, the personality of the classroom community, the response of unique classes to these activities, and the content or unit being covered. These adjustments are not discussed in this book. These are the details added to lesson plans by individual teachers. Adjustments

are also best implemented using classroom management skills and teaching strategies that individual teachers deem best based on their own personality and teaching style. So we leave the job of making these lessons come alive to you.

A good number of readers may still have reservations, but we hope we have addressed some of the more common, immediate hesitations. Now we would like to describe how we begin setting up our scientific community, which is the focus of our next chapter.